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GEOLOGIC AND MINERAL AND WATER RESOURCES INVESTIGATIONS IN WESTERN COLORADO USING ERTS-1 DATA: PROGRESS REPORT II

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16. Abstract Preliminary geologic interpretations of selected ERTS-1 scenes in central and western Colorado indicate that lithologic discrimination and structural interpretation can be made on ERTS-1 images. Generally, lithologic units mapped on ERTS-1 images are composed of 2 or more recognized geologic formations and should more correctly be referred to as "remote sensing units". Faults mapped on ERTS-1 images in western Colorado correspond well with faults mapped on the geologic map of Colorado (1:500,000). Stratigraphic offset was easily detected along faults as short as 3km; it is anticipated that faults as short as ½-1km should be identifiable. Several previously unmapped major linear features, possibly faults, were detected and mapped on ERTS-1 imagery. Stereoscopic analysis of ERTS-1 imagery greatly enhances the capability of the interpreter. Structural features and lithologic contacts are more accurately traced and more "remote sensing units" (lithologic) can be defined. Ambiguous or questionable structural interpretations are commonly quickly resolved by stereoscopic analysis.

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PREFACE

On 30 June 1972 a contract was awarded to the Colorado School of Mines for research in the interpretation of ERTS-1 imagery and supporting aircraft data and their application to mineral and water resources investigations. This work is being done in the Department of Geology by five professors, one research associate, and three graduate student research assistants. The work consists primarily of the following studies:

1) Identification and discrimination of
   (a) rock types and surface composition
   (b) geologic structures
   (c) geomorphic phenomena
   (d) mineral resources
   (e) water resources
   (f) volcanic phenomena
2) Evaluation of ERTS imagery for geologic applications
3) Processing and enhancement techniques applied to ERTS imagery
4) Atmospheric effects on remote sensing data

ERTS images covering most of Colorado have been received, however, most of the central and north-central part of the state has been obscured by moderate to heavy cloud cover on each ERTS overpass. In less cloud covered areas, the quality of the imagery and the amount of surface detail that can be seen exceeds earlier expectations. Preliminary geologic interpretation of several scenes of MSS imagery indicates that considerable lithologic and structural information can be extracted.

Side lap of approximately 30 percent, at these latitudes, permits stereoscopic viewing of about 60 percent of each image. This is of great value in geologic analysis, and terrain analyses in general. If at all possible, complete stereoscopic coverage should be obtained, perhaps by offsetting the ERTS-2 ground track one-half frame from that of ERTS-1.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

This report summarizes the work conducted by the Colorado School of Mines during the period 31 June - 11 November 1972 under contract NAS5-21778 to the National Aeronautics and Space Administration/Goddard Space Flight Center for the purpose of investigating the application of Earth Resources Technology Satellite (ERTS) data to identify and discriminate geological phenomena in central and western Colorado. Included are lithologic, structural, geomorphologic, and mineral and water resources studies.

During the reporting period, aircraft support data from NASA missions 205, 211, and 213 were received, indexed, cataloged, and evaluated. Similarly, a steady flow of ERTS-1 images covering a major portion of Colorado has been received, cataloged, and indexed; these consist of imagery from 5 cycles, commencing in early August and continuing until the end of the reporting period. Ground investigations in several detailed test areas in the state were conducted during the early part of the reporting period, and geologic interpretation of existing remote sensing data was done prior to receipt of ERTS-1 imagery and supporting aircraft data. Solar radiation and rock reflectance measurements in support of the study of atmospheric effects on remote sensing data were conducted during the 7 September 1972 ERTS-1 pass over the Cripple Creek area in the southern Front

Range. Preliminary geologic interpretation of selected ERTS-1 scenes have been made.

ERTS-1 AIRCRAFT SUPPORT MISSIONS

NASA Missions 205 and 211

Two high altitude aircraft missions have been flown in support of the Colorado School of Mines ERTS-1 program. Mission 205 was flown during June 1972 and Mission 211 during September 1972. Data from both missions have been received and indexed. Evaluation of the quality of the data is in progress at the present time.

Data Acquisition: Data were acquired by instruments on the RB57F Aircraft (NASA 925) from an average altitude of 55,000' above sea level resulting in elevations of nearly 50,000' above mean terrain. The data on Mission 205 were acquired on 2, 14, and 15 June 1972; Mission 211 data were acquired on 16, 17 and 21 September 1972. The data include color, color IR and multiband photography and daytime thermal IR imagery. Table 1 gives the specifications for the photography acquired.

Date Received: Mission 205 data were received during October 1972; Mission 211 data were received during November 1972. The Mx 205 data includes 14 north-south flight lines of photography flown from near the northern border of Colorado to near the southern border of Colorado. The 18 lines on Mission 211 were flown in the same general configuration. Four-times enlargements of Mx 205 thermal infrared imagery are the only requested data products not received at the time of this

TABLE 1. Mx 205/211 Photographic Specifications

CAMERA	LENS	FILM	FILTER	PHOTOGRAPHY
RC-8	6"	SO-397	2A	Color
RC-8	6"	2443	12	Color IR
Zeizz	12"	2443	12	Color IR
Hasselblad	40mm.	2402	25	Blue
Hasselblad	40mm.	2402	57	Green
Hasselblad	40mm.	2424	89B	B/W IR
Hasselblad	40mm.	SO-356	HF 3	Color
Hasselblad	40mm.	2443	12 + cc 20B	Color IR

report. Photography requested over the San Juan Mountains could not be flown on either mission due to poor weather conditions.

Indexing and evaluation: Coverage of Mission 205 and 211 is shown in Figure 1.

Data Quality: Data from both missions are good. Excellent resolutions and exposures characterize the photography and the thermal IR imagery is of generally good quality. Both side-lap and end-lap appear adequate for geologic work with stereoscopic equipment. In addition, cloud cover is generally only a small percentage of the area, and most areas are cloud-free on one of the missions.

NASA Mission 213

On 9-14 September 1972, the NASA NC130B acquired remote sensor data over four selected subsites within the Colorado School of Mines ERTS test site. These four sites are Golden, Leadville, Canon City and the San Juan Mountains (Figure 2). Each of these areas is the site of an on-going detailed ERTS remote sensing investigation. Color and color IR photography was acquired to support ground evaluation of ERTS data and multiband photography and MSS data were acquired to help gain a better understanding of the use of multispectral sensors.

Color and Color Infrared Photography: Color and color infrared (IR) photography were obtained over all areas in the non-contingency flight request. The results of the evaluation of this photography is summarized in Table 2.

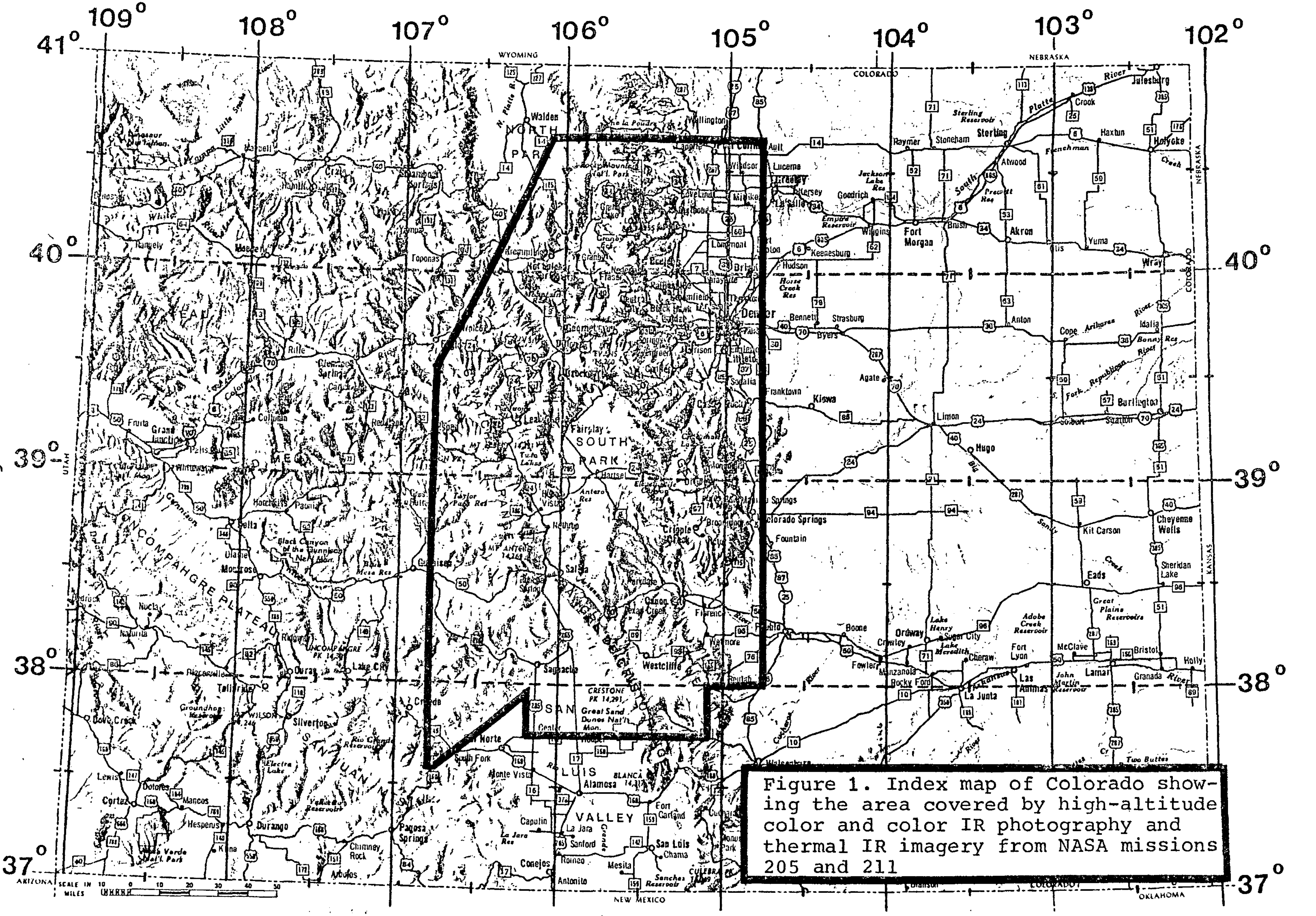

Figure 1. Index map of Colorado showing the area covered by high-altitude color and color IR photography and thermal IR imagery from NASA missions 205 and 211

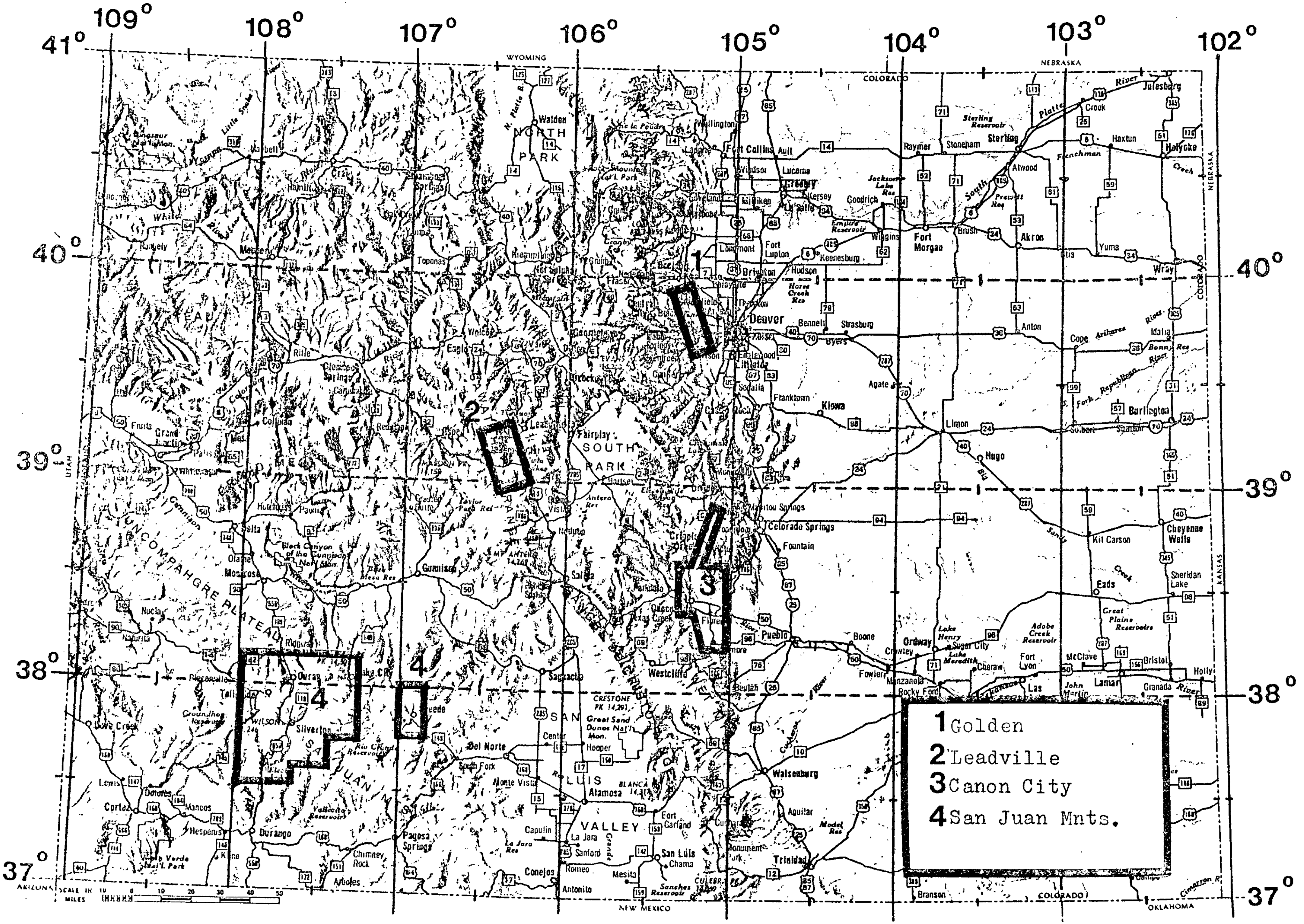

Fig 2. Index map of Colorado showing areas of low-altitude photographic coverage on Mx213.

TABLE 2. Summary of Broad Mission Parameters Evaluated

Area	Flightline accuracy	% coverage	Cloud loss (%)	sufficient Sidelap	end lap (60%)
Canon City	Good	100	25	Yes	Yes
San Juan Mts.	Good	100	10	Yes	Yes
Golden	Good	100	5	Yes	Yes
Leadville	Good	100	5	Yes	Yes

Eighteen additional image quality factors also were evaluated providing an objective measure of the overall data quality. Both the color and color IR photography provided generally good to excellent positive transparencies. Positive prints of the color and color IR photography have not been received.

Highly-variable terrain brightness caused some problems in getting good exposures in all the photographed terrain. Due to this variation in terrain brightness, fifteen percent of the photography was rated as having variable exposure (i.e.-not normal exposure). However, this photography was rated as acceptable. It is concluded that the photographer handled the difficult situation very well and that the processing was good.

Multiband Photography: Multiband photography was flown to discriminate between rock types and to aid in understanding the multispectral scanner data. Multiband photography was obtained in the Canon City and Golden areas using the following film/filter combinations:

CAMERA	FILM/FILTER
I^2S	ERTS configuration
Hasselblad 4	2424/89B

CAMERA	FILM/FILTER
Hasselblad 5	2402/8
Hasselblad 7	2402/92
Hasselblad 8	2424/87C

Mission parameters were essentially the same for the I^2S and Hasselblad photography except that no sidelap was obtained with the I^2S camera. An evaluation of some significant parameters of the multiband photography are listed in the Table 3 below. Overall, the multiband photography seems to have been properly acquired.

		I^2S	Hass.4	Hass.5	Hass.7	Hass.8
Exposure (%)	Normal	90	81	81	81	81
	Under	5	19	19	19	19
	Over	5				
	Variable					
Contrast (%)	Normal	80	81	81	81	81
	Flat	20	19	19	19	19
Tone		Good	Good	Good	Good	Good
Summary Evaluation		Good	Good	Good	Good	Good

TABLE 3. Evaluation of MX 213 Multiband Photography.

Multispectral Scanner: Multispectral scanner (MSS) data were obtained over selected areas at the Canon City and Golden sites. Approximately 88 percent of the requested data was obtained. Data loss was due to malfunctions of a few channels of the MSS; make up of this data will not be requested at this time. The flight-line accuracy was excellent and cloud loss was not significant.

A photographic copy of the imagery from Channel 6 was used for indexing the MSS data over the Golden and Canon City sites. This imagery is for indexing purposes only, and cannot be used for geologic interpretation. High-quality imagery will be requested for selected areas at a future date.

Aircraft Data Applications

Aircraft remote sensing data, mainly color, color IR, and multiband photography, are being applied to the CSM/ERTS-1 project in a variety of ways; a few specific examples are listed below.

1) Areas where rock discrimination can be made on ERTS-1 imagery are isolated and documentation is made of the physical characteristics of the outcrops discriminated. Aircraft data are used to document tonal, textural, topographic, vegetation, etc., differences that allowed discrimination to be made.
2) Areas where similarly configured rock units occur, but where discrimination cannot be made are isolated. Aircraft data are used to help determine the surface conditions that hindered discrimination.
3) Areas where known structural features (folds, faults, joint sets) occur are isolated on ERTS-1 images. It is then determined whether the known structures can be detected. Aircraft data are used to determine the cause of textural and tonal differences noted, if any.
4) Areas where known landforms occur are isolated on the ERTS-1 imagery. Aircraft data are used to document the geometry and dimensions of the landforms as well as to help determine the cause of texture and tone noted on the imagery.

5) Areas where known mineral deposits occur are isolated on ERTS-1 imagery. Aircraft data are used to help document the surface manifestations of the deposits and the ERTS imagery is analyzed for these manifestations.

6) Areas where water resources are known to occur are isolated on ERTS-1 imagery. Aircraft data are used to document the type, scale, and physical characteristics of the surface manifestations (lakes, ponds, reservoirs, vegetation anomalies, etc.) of the water resources, and the ERTS-1 imagery is analyzed for these surface manifestations.

7) ERTS imagery is studied for new geologic information on 1 - 6 above. Aircraft data are used to help document the discovery of newly discovered geologic phenomena.

8) Aircraft data are supplied to detailed and reconnaissance ground studies in specific geographic/geologic areas of interest.

ERTS-1 SATELLITE IMAGERY

Fourty-four scenes of ERTS-1 MSS (and some RBV) imagery have been obtained over Colorado. The aerial coverage of the state is shown in Figure 3. Statewide coverage is nearly complete, except for the area north of Denver and two areas along the eastern border of the state. The area north of Denver has been obscured by clouds during all five cycles to date, and the area east of 104° W longitude is outside of the area included in the Colorado School of Mines investigations.

Essentially cloud-free imagery has been obtained, on one cycle or another, of all except the central part of the state. Although the cloud distributions are different for different cycles, significant portions of the central part of the state have been continually obscured by clouds in imagery from all of the cycles.

ERTS-1 imagery is indexed immediately on receipt using the U.S. Geological Survey 1:1,000,000 base maps of Colorado and surrounding states. An evaluation of image quality and cloud cover, independent of the NASA/GSFC evaluation, is also made. The 1:1,000,000-scale indexes are transferred to small-scale, page-size maps which are ultimately compiled to produce a single index map for each ERTS-1 cycle. The Colorado ERTS-1 coverage for cycles I-V is shown in the Appendix.

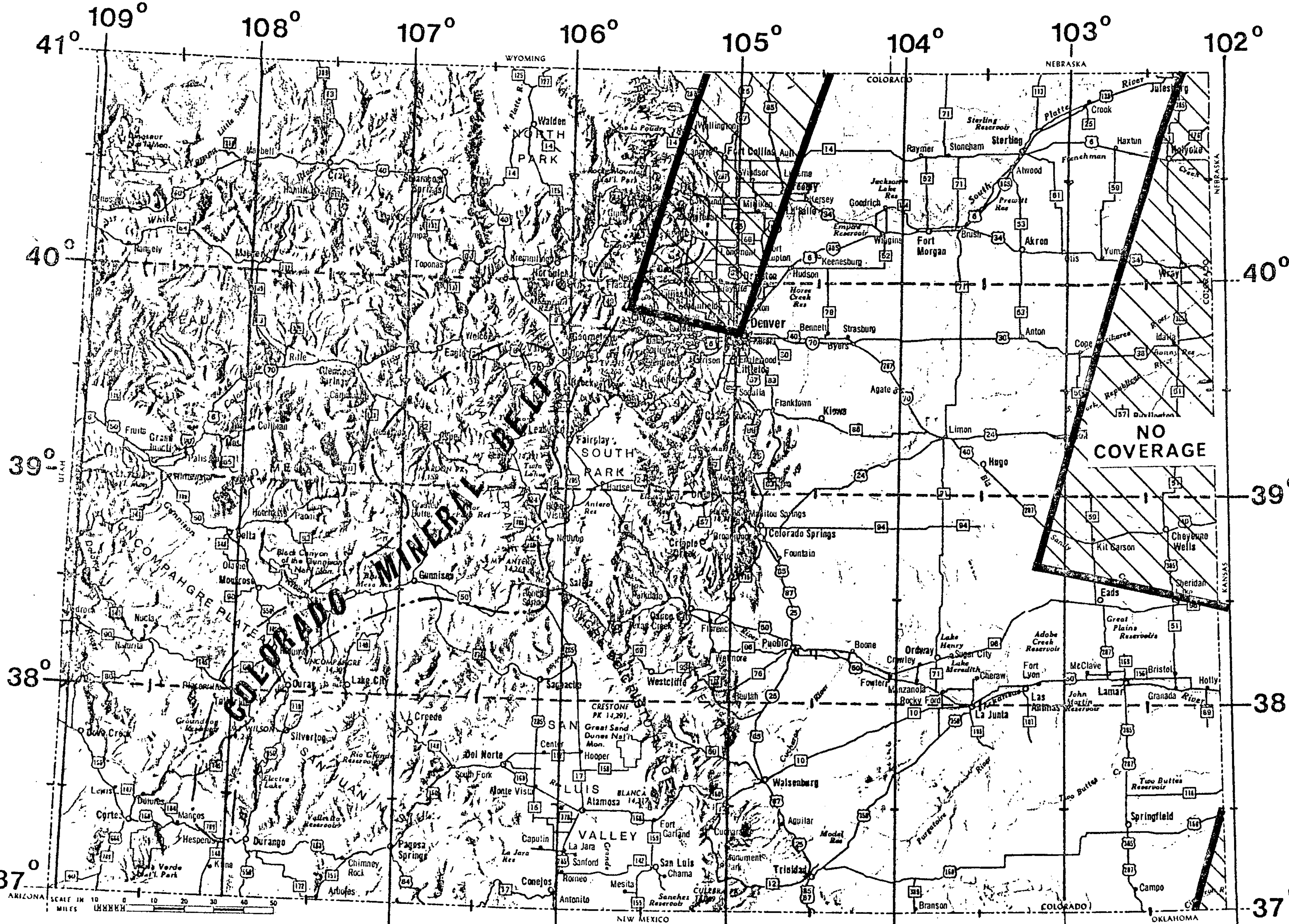

Figure 3. Index map of Colorado showing coverage of ERTS-1 imagery received from Cycles I-IV.

The correspondence between the images and the 1:1,000,000 state base maps is noteworthy. Numerous errors in positioning of the tick marks denoting latitude and longitude on ERTS-1 images were discovered. A number of tick marks were in error by as much as 6.5mm (6.5km), and few were off nearly 13mm (13km).

For each scene, 70mm negatives, 70mm positive transparencies, and 9.5-inch positive transparencies were received as requested. Most of the 70mm negatives are too dense for use in routine photographic enlarging, and both the 70mm negatives and positive transparencies contain abundant Newton rings making them unsatisfactory for detailed geologic interpretations. The 9.5-inch positive transparencies are generally good quality, although a few images are totally or partially "fuzzy", due apparently to slight movement or uneven contact during duplication.

GROUND INVESTIGATIONS

Ground geologic studies in support of the CSM/ERTS project have been conducted in several areas of the state: Leadville, Marshall Creek, Salida, central San Juan Mountains, and Canon City (Figure 4). These studies have been concerned with establishing ground control in selected areas which could be used during subsequent analysis and interpretation of ERTS-1 and supporting aircraft data. Where available, aircraft remote sensor data acquired by NASA for the CSM Bonanza Project (NGL 06-001-015) or from other sources were used during preliminary geologic analysis and during field mapping.

Leadville Area[1/]

Ground investigations carried out in the Leadville area (Figure 4) during the report period of 31 June - 11 November, 1972, were directed toward field checking the results of geologic interpretation of aerial photography and imagery in the Mosquito Range south of Union Creek and north of Buffalo Peaks. The rocks present in this area are predominently Precambrian metamorphic rocks; the area is shown as Precambrian granite or undifferentiated Precambrian rocks on available geologic maps. The area includes two small mining districts: 1) the previously mapped Weston Pass district, which includes some Paleozoic

[1/] Dennis L. Bruns

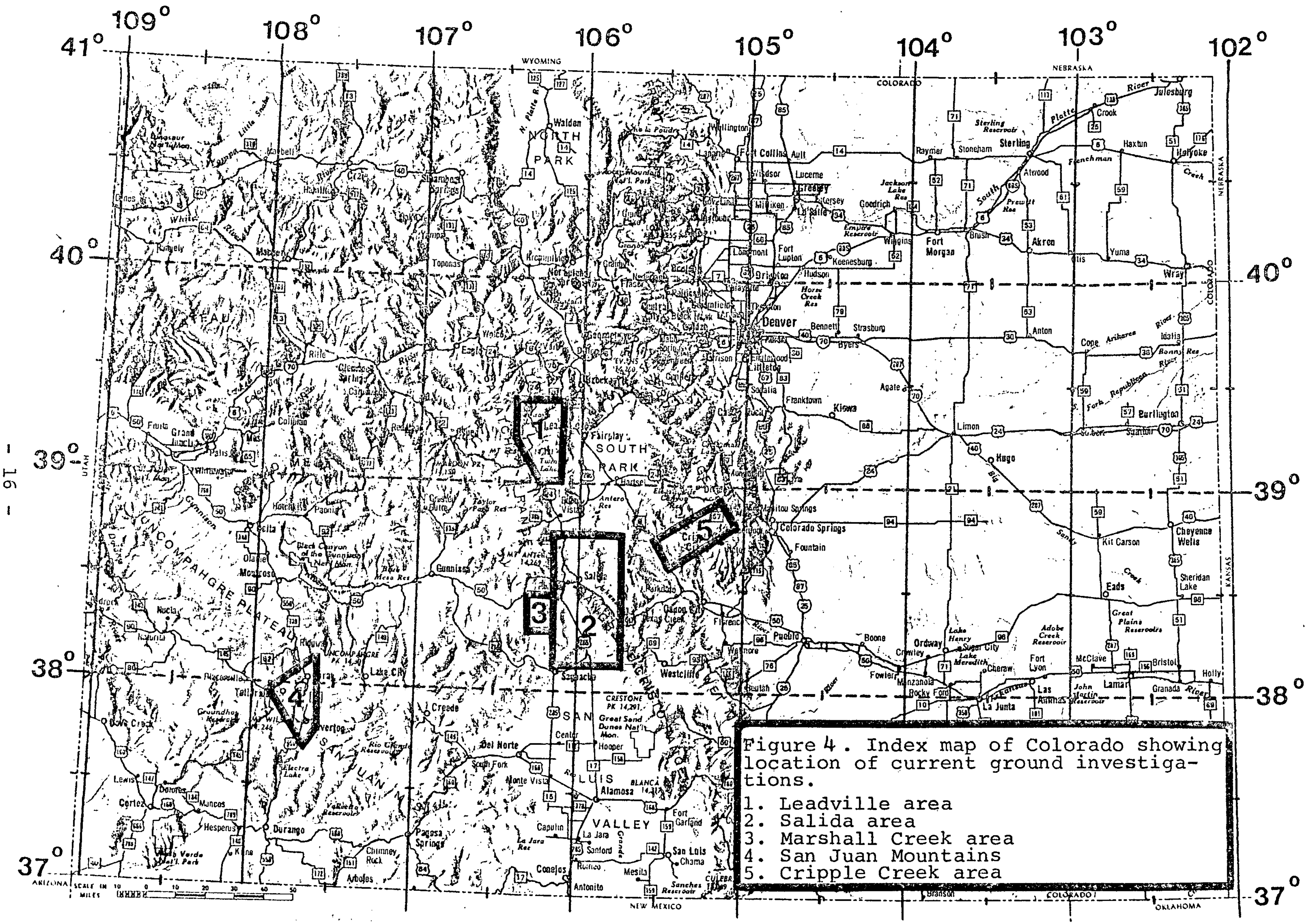

Figure 4. Index map of Colorado showing location of current ground investigations.

1. Leadville area
2. Salida area
3. Marshall Creek area
4. San Juan Mountains
5. Cripple Creek area

6

sedimentary rocks, and 2) the Granite mining district, for which no detailed mapping is available (the area is included in reconnaissance-scale mapping done by the U.S. Geologic Survey as part of an unpublished geophysical study).

Granite District: Field checking in the Granite mining district (Lake and Chaffee counties, Colorado) generally verified that the lineament pattern mapped on aerial photos are northeast-- and northwest-trending faults. A transitional contact between layered Precambrian gneiss and schist (probably metamorphosed Precambrian sediments intruded by granite) and massive Precambrian granite with engulfed blocks of gneiss and schist was mapped, partly from photointerpretation, and partly from field observation. In addition, several small areas of amphibolite gneiss, possibly representing pre-metamorphic intrusives, were observed. Several areas, mapped from aerial photography as alteration, were found to be altered, and areas mapped as Tertiary intrusives were found to be rhyolite dikes. Several folds were mapped in the gneiss and schist.

It was generally verified that alteration and mineralization in the Granite mining district are restricted to the vicinity of faults and fractures except in a few cases where a favorable lithologic layer in the gneiss and schist controlled alteration and mineralization. Alteration and mineralization were most intense where northwest- and northeast-trending faults intersect. Alteration and mineralization were also limited in most cases to the Precambrian gneiss and schist; very little alteration and mineralization were found in the Precambrian granite. From evidence found on old mine dumps, references in literature, and conversation with local residents, it seems probable that the economic mineralization in the Granite mining district consisted of gold in pyrite (or free gold and/or gold in iron oxides in the zone of weathering) with small amounts of chalcopyrite and galena occasionally present.

Weston Pass District: Field checking in the Weston Pass area verified several minor faults not previously mapped. Areas photomapped as alteration were found to be altered. Several large lineaments could not be verified as faults due to soil and plant cover.

Most of the faults mapped from photogrpahy and imagery and verified by field checking would have been difficult, if not impossible to map solely by ground investigation due to soil and plant cover, and uniformity of lithology. Springs, which could be seen on the ground, were frequently found along faults and in a few cases displacement of identifiable rock units or changes in strike and dip across a fault could be found in the Precambrian gneiss and schist and the Paleozoic sedimentary rocks. In general, however, the only ground evidence for faulting consisted of slicken--slides and/or brecciated Precambrian rock found in the vicinity of a suspected fault. In most cases such evidence of faulting could be found only if one knew in advance where to look or was doing extremely slow and detailed ground mapping.

Salida Area[2]

During the last 3 years, ground studies and aircraft remote sensing have been applied to geologic mapping in an area of approximately 1,100 square miles centered around the town of Salida, Colorado (Figure 4). A detailed geologic map at a scale of 1:62,500 has been prepared for the area. A relatively large area was chosen so that the completed geologic map of the area could be used to evaluate remote sensor data acquired from space, and with the recent receipt of an ERTS-1 image (I.D. #1028-17135) including the study area, the evaluation will begin.

The study will involve 1) correlating known geologic features with ERTS-1 imagery interpretations, 2) determining the reason why specific known geologic features either can or cannot be recognized and identified on ERTS-1 imagery, and 3) recognizing and identifying new geologic features on ERTS-1 imagery. Aircraft remote sensing data will be used primarily to help in 2) above.

Marshall Creek Area[3]

Geologic field mapping was conducted over 42 sq. miles of the upper Marshall Creek drainage basin, Saguache County, Colorado, during the 1972 summer field season. Marshall Creek flows westerly from the Continental Divide at Marshall Pass. Field mapping was accomplished using Mission 184 color and color IR photography and Mission 101 color photography. Geologically, the area is located at the southern extension of the Sawatch uplift,

[2] D. H. Knepper

[3] James L. Evans

and along the northern contact of the San Juan volcanic field with the basement Precambrian and Paleozoic rocks.

San Juan Mountains/Stratigraphy[4/]

Ground investigations were carried out from 1 July to 27 August, 1972, in an area south of Silverton, Colorado (Figure 4). The area of study extends from the Precambrian-Paleozoic contact just west of the Amimas River to about 3 miles west of U.S. highway 550, and from the sedimentary-igneous contact, about 6 miles south of Silverton, south to the Coal Bank Pass area. The study area includes about 28 sq. mi.

Methods: The following methods were used in this stratigraphic study:

1) Detailed geologic mapping on U.S. Forest Service B/W air photos at a scale of 1:20,000. This work included:

   a) Plotting of contacts,

   b) Plotting of structures (fault traces and fold axes)

   c) Measurement of bedding attitudes with a Brunton compass.

2) Sampling and description of Paleozoic lithologies

3) Section measurement in the Pennsylvanian Hermosa Formation with a Jacob's Staff and Brunton Compass. This work included:

   a) Measurement of thicknesses of individual genetic units and of the complete formation

   b) Detailed descriptions of lithologies, sedimentary structures, and constituents of each genetic unit

   c) Sample collection in unusual, typical, and fossiliferous units

[4/] Robert Spoelhof

d) Correlation of members of the Hermosa Formation and of individual beds by "walking the outcrop" and by the method of stratal continuity

e) Sampling of typical, unusual, and fossiliferous beds in the entire area.

Results: This field study and those of others (C.S.M. faculty, 1969-1971) has suggested that there are structures of at least two origins in the area. A small laccolith occupies about one square mile in the center of the area. Intrusion of this body produced at least one major fold in the sedimentary country rocks. Forceable intrusion also resulted in small fractures in the vicinity of the intrusion.

Other structures in the sediments were produced by tectonic movements in the Precambrian basement rocks. These structures include major and minor faults and their associated drag folds. It is believed that these faults are in part Paleozoic in age and in part Tertiary.

Detailed mapping, description, and section measurement in the Pennsylvanian sediments have delimited three members of the Hermosa Formation. The Upper Member is about 500 feet of shale, siltstone, medium-grained sandstone, and very coarse-grained arkose with subordinate fossiliferous limestone. The Middle Member is 350 to 400 feet of very-thick-bedded fossiliferous limestone with subordinate arkose, siltstone, and shale. The lower Member is 1,700 feet of arkose, sandstone, siltstone, and shale with subordinate limestone. One measured section delimited 50 feet of limestone with subordinate sandstone at the base of the formation. Further investigation may reveal the presence of the limestone in other parts of the area.

Tracing of limestone beds showed a general abrupt thickening from north to south along strike as the beds cross into an area of major east-west faults.

Present investigations: All samples are now being studied to more exactly determine the composition and variations of constituents. Particular attention is being given to the limestones so that the type, amount, and direction of change in the faunal assemblages can be determined. The preliminary objective of this study is to gain an understanding of the depositional environment and history of the region.

San Juan Mountains/Mineral Deposits[5/]

Field and office studies were conducted concurrently during July and August 1972 in the Yankee Boy basin - Ouray - Imogene basin - Silverton caldera area of the central San Juan Mountains of Colorado. Office studies consisted of plotting the vein structures and major fracture systems visible on conventional black and white aerial photographs (1:20,000). Field studies consisted of measuring 1) strike and dip of barren and metallized veins, 2) widths of hanging and foot wall alterations, and 3) major linear and fracture systems. Underground, as well as surface measurements, were made in Yankee Boy and Imogene basins. Chip samples were cut across vein structures in order to analyze for possible base metal and other geochemical anomolies.

Alteration patterns in the study area are of two types: 1) narrow zones occurring along the foot walls and hanging walls

[5/] Dr. Robert M. Hutchinson

of individual veins and vein structures, and 2) a broad blanket-type that is peripheral to caldera structures. Alteration types present in the area include argillic, quartz-sericite, ferruginous, propylitic, and chloritic.

From September to November, prior to receipt of photographic data acquired over the study area during NASA Mission 213, color prints (1:20,000) of U.S. Geological Survey photography (1967) were used for preliminary regional analysis of vein structures in the investigation area. The color prints were interpreted stereoscopically using an Old Delft Scanning Stereoscope II. Veins and vein structures were plotted in red and major joint systems in black on clear plastic overlays. When the interpretations are completed, a vein trend map will be constructed and the frequency of veins mapped on the color photography will be compared to existing geologic maps as a statistical measure of the utility of the color photos. Follow-on investigation will be geared toward expanding the study area using Mx 213 low-altitude photography, high-altitude photography to be flown by NASA (RB57) in June 1973, and ERTS-1 imagery, heavily supported by field studies.

Preliminary analysis of the vein trends indicates that the vein structures trend N35-50^{o}W and occur at spacings of 800 feet and 1,600 feet. The veins range from 1 to 4 miles in length and several to 50 feet in width. At least three different ages of vein structures and metallization are present, and at least four major sets of fractures exist and are, in part, related time-space wise to the vein structures. Time-space relations between both individual and intersecting vein structures are being recorded and plotted using underground data from the Camp Bird mine. Some of the same vein intersections occur on surface exposures and are clearly visible on color photographs.

In summary, analysis of black and white and color photos, combined with surface and underground investigations, has delineated a N35°E-trending, 3 x 9-mile elongate strip possessing maximum vein structure development. This area is located between the Stony Mountain intrusive and the Silverton caldera, and includes the mining regions in both Yankee Boy and Imogene basins. Vein structures throughout this area trend N35-50°W. Preliminary structural analysis indicates rise and emplacement of the Stony Mountain and Silverton plutons could have produced maximum compressional-tensional-dilational effects throughout the N35°E-trending strip.

Cripple Creek Area[6/]

The major activities in the Cripple Creek area during this reporting period consisted of 1) organizational tasks in preparation for the 7 September ERTS-1 overpass of the site, 2) ground measurements during the ERTS-1 overpass, and 3) photo-interpretation of aircraft remote sensing data. The location of the Cripple Creek area is shown on Figure 4.

Pre-launch Activities: Two field trips were conducted during the third week of June 1972 for the purpose of collecting baseline atmospheric data prior to ERTS-1 satellite launch. Dr. H. Smedes and R. Watson, USGS, accompanied Martin Marietta Corporation personnel on these trips. Two objectives were set:

[6/] James R. Muhm

1) To locate suitable candidate atmospheric measurement sites for the overall geographic range of our area of interest (i.e., from Florissant north of Cripple Creek to the Great San Dunes).

2) To record first measurements of atmospheric parameters at ten individual locations within our selected ERTS test site.

Candidate sites for measuring atmospheric parameters during ERTS-1 overpass were selected. Each site was chosen on the basis of its altitude, geologic, topographic, and vegetative environment and its geographic position within the overall test site. Actual measurements made pertain to the optical transmission properties of the atmosphere above each of the sites as well as the atmospheric clarity above each site. Optical transmission was determined using a Kahlsico pyrheliometer filtered to the following spectral bands:

1)	300 to 2800 nanometers	6)	300 to 630 nanometers
2)	525 to 2800 nanometers	7)	300 to 700 nanometers
3)	630 to 2800 nanometers	8)	525 to 630 nanometers
4)	700 to 2800 nanometers	9)	525 to 700 nanometers
5)	300 to 525 nonometers	10)	630 to 700 nanometers

Atmospheric clarity was measured using a Kahlsico pyranometer to establish the ratio of diffuse-to-total solar radiation. In addition, pressure, temperature, relative humidity, and a plot of topographic elevations as seen radially to the test site were recorded in each case. Of the ten sites planned, only three sites were sufficiently cloud-free on the day of the field trip to allow solar measurements. These three were at Howard, Hayden Pass, and Gribble's Run at the south end of the Thirtynine-mile volcanic field. Pressure, temperature, relative humidity, and topographic profiles were recorded at all ten sites.

Two specific geologic control sites were selected for field study. Site 1 is located in the Granite Hills south of Florissant. Surface outcrop is composed of weathered granite of the Pikes Peak batholith. Site 2 is located on Cross Creek at the north end of the Thirtynine-mile volcanic field, near Elevenmile Reservoir. Surface outcrop here is composed of Oligocene basalts apparently extruded from the Guffy Center. Hemispherical reflectance spectra were recorded at both sites during the satellite overpass on 7 September.

Ground Measurements During ERTS-1 Overpass: Four persons occupied ground stations during the ERTS-1 satellite pass of 7 September 1972. Two persons manned Martin Marietta Armospheric Sciences Mobile Laboratory at the Granite Hills site on 6 September. This site, about seven miles south of Florissant at 38.83^{o}N, 105.27^{o}W, is located on a typical outcrop of Pikes Peak Granite. Data collection commenced on the afternoon of 6 September and included measurements of direct, diffuse, and total incident solar radiation, as well as reflectance spectra of the granite itself.

Additionally, during satellite overpass on 7 September, two persons occupied a second ground site located at Cross Creek on rock outcrops of the Thirtynine Mile Volcanic Field at 38.88^{o}N, 105.60°W. This rock type occurs in a wide area to the south of Eleven Mile Reservoir and comprises the second major rock type which we wish to distinguish from the Pikes Peak Granite using ERTS-1 data. Measurements of solar radiation and rock reflectance were made over a four hour period.

Imagery resulting from the ERTS-1 overpass on 7 September has not yet been received; observations at the test site, however, indicate a substantial degree of cloudiness which probably obscured much of the test site.

Preparations were made for field measurements contemporaneous with ERTS-1 overpass on 31 October. Unfavorable weather forecasts led to cancellation of the trip.

Photo-Interpretation: Preliminary photointerpretation of about 80% of the Cripple Creek area was performed using existing U-2 black/white photography. The objective of the photogeologic examination was to observe major structural and stratigraphic features expected to be detectable on ERTS imagery. Special effort will be made to observe on ERTS imagery the southwestern border of the Pikes Peak batholith which is easily visible on the U-2 photography as a pronounced topographic anomaly between the batholith and the more resistant wall rock.

Color aerial photography from NASA Aircraft Mission 205 has been received. The photography was exposed from the RB-57 at an approximate altitude of 60,000 feet and provides good coverage of the ERTS-1 test site. Interpretation and comparison with ERTS imagery is now underway.

ERTS-1 DATA INTERPRETATION

With most of the preliminary organizational tasks completed or nearing completion, the major task of interpretation and evaluation of ERTS-1 imagery and supporting aircraft data has begun. This task, along with field studies, will be the major effort for the duration of the project.

Aircraft Support Data:

Remote sensing data from NASA missions 205, 211, and 213 was recently received at the Colorado School of Mines and cataloging and indexing of the data has just been completed. Consequently, little detailed geologic interpretation of the data has been done. First look evaluation of the aircraft data indicates that it will play an important role in fully utilizing and understanding ERTS-1 imagery by 1) providing an intermediate scale of observation between ground data and space data, 2) helping to explain more fully the textural and tonal variations identified on ERTS-1 images, and 3) providing the capability for more rapid and more efficient ground investigations.

ERTS-1 Satellite Imagery

The initial interpretations of ERTS-1 images have been conducted primarily as a learning process in which the interpreters were concerned with becoming acquainted with 1:1,000,000-scale images and with developing routine approaches for ERTS-1 image interpretation. Consequently, most interpretations made during this reporting period are preliminary; more thorough and more detailed interpretations will be performed during the next reporting period.

Western Colorado[7/]

Approximately 6 hours was spent studying an ERTS-1 image over west-central Colorado for which the interpreter had only a general geologic knowledge. The ERTS-1 image (I.D. #1066-17251-7; See Figure 8 of Appendix) was studied for lithologic contacts and major structural lineaments. Band 7 was chosen for the study because it displays the greatest overall contrast. Interpretation was conducted on a 9.5-inch positive transparency on a light table. A piece of clear acetate was placed over the transparency and contacts and lineaments were mapped with triple-o drafting pens. The interpretation was compared to the existing 1:500,000 geologic map of Colorado (1935) in order to check: 1) accuracy and number of formational contacts mapped, 2) accuracy and number of known structural lineaments mapped, and 3) number of structural lineaments mapped which do not appear on the state geologic map.

Preliminary results indicate that lithologic contacts between known geologic formations in the area cannot be mapped on ERTS-1 images in the detail present on the geologic map of Colorado. Generally, the stratigraphic units mapped on the ERTS-1 image actually consist of 2 or more recognized geologic formations, and should more correctly be referred to as "remote sensing" units. Major known structural lineaments were mapped on the ERTS-1 image in a detail only slightly less than exists

[7/] D. H. Knepper

on the geologic map of Colorado. Several strong linear features were detected and mapped on the ERTS-1 image which are not shown on the state geologic map. These new linear features have not been studied in the field, so their origin remains in question.

After the initial interpretation was made, the western third of the ERTS-1 image was studied stereoscopically using the adjacent image (I.D. #1031-17311-5) to produce a stereo pair. Although no statistical stereo non-stereo comparison was made, some general ideas were formulated. Utilization of stereoscopic viewing appears to be an important asset for geologic interpretation of ERTS images. Structural features and lithologic contacts could be traced more accurately and several new "remote sensing' units were identified. Several ambiguous or questionable structural interpretations were quickly resolved by stereoscopic viewing.

Pikes Peak Batholith[8/]

Between 1957 and 1971, a vast amount of structural observations have been made over an area of about 2,000 square miles encompassing the Pikes Peak batholith of the southern Front Range of Colorado. Interpretation of ERTS-1 imagery and high-altitude U-2 black and white photos of the batholithic terrain has just begun and specific results cannot be clearly defined. In general terms, however, it can be stated that the ERTS-1 and U-2 data are proving invaluable in synthesizing structural and tectonic interpretations of the Pikes Peak batholith. The

[8/]Dr. R. M. Hutchinson

planimetric accuracy of structural, tectonic, and petrologic observations on this small-scale data permits unusual geologic insight in interpreting the evolution of this segment of the Precambrian crust of the central Colorado Rockies. Indeed, old ideas are being refined and new interpretations developed.

SIGNIFICANT RESULTS

Lithologic Surveys

Preliminary analysis of an ERTS-1 image over western Colorado (1066-17251-7) indicates that many lithologic contacts can be mapped on ERTS-type imagery. The stratigraphic subdivision mapped on the image is not as fine as depicted on the geologic map of Colorado (1:500,000) and most "ERTS stratigraphic units" are actually composed of 2 or more recognized geologic formations. Use of stereoscopic analysis greatly enhances the capability of the interpreter to recognize and map lithologic units in a stratigraphic sequence, particularly in high-or moderate-relief terrain.

Structural Surveys

Major faults were mapped on ERTS image 1066-17251-7 (Western Colorado) and the results were compared to the geologic map of Colorado (1:500,000). The comparison indicates that the major faults in the scene area were mapped in a detail only slightly less than exists on the geologic map of Colorado. In addition, several strongly-expressed linear features, possibly faults, were detected and mapped on the ERTS-1 image which are not shown on the state geologic map. Several ambiguous or questionable structural interpretations were quickly resolved by stereoscopic analysis.

PROGRAM FOR NEXT REPORTING PERIOD

During the next reporting period emphasis will be placed on the geologic interpretation of ERTS-1 imagery and supporting aircraft data. The primary goals of ERTS-1 imagery analysis will be 1) to determine what kind and scale of geologic phenomena can be interpreted from the imagery alone, from space data plus aircraft data, and from space data, aircraft data, and ground data combined, 2) to determine which spectral bands are best suited for geologic interpretation in Colorado, and 3) to investigate various interpretative techniques including conventional photogeology, stereoscopic analysis, and color additive viewing.

NEW TECHNOLOGY

No new technology was developed during the time period covered by this report.

CONCLUSIONS

The bulk of the ERTS-1 and supporting aircraft data requested by the Colorado School of Mines for the first 10 months of NASA contract NAS5-21778 has been acquired, cataloged, and indexed, and the quality of the various data has been evaluated. Research personnel are now free to devote full-time to the analysis, interpretation, and evaluation of ERTS-1 data for geologic applications.

Ground investigations and preliminary photo-interpretations of previously existing remote sensing data in several areas of Colorado have provided important geologic cornerstones for the subsequent interpretation and geologic evaluation of ERTS-1 and supporting aircraft data. It is anticipated that documentation of geologic phenomena observed in the field can be applied to regional geologic interpretations using ERTS-1 and supporting aircraft data.

The results of preliminary interpretations of ERTS-1 images over portions of central and western Colorado indicate that the images can be effectively applied to regional geologic studies and, hence, toward meeting the objectives of this investigation. Stereoscopic analysis of ERTS-1 images, where possible, significantly increases geologic interpretation capability for lithologic discrimination and structural analysis.

RECOMMENDATIONS

Based on the preliminary results of geologic interpretations of ERTS-1 images of western and central Colorado, it has been found that use of stereoscopic analysis greatly aids in lithologic and structural studies. It is recommended that users of ERTS-1 images for geologic studies be encouraged to apply the limited stereoscopic capability of ERTS-1 imagery to their investigations.

APPENDIX: Index maps of Colorado showing coverage of ERTS-1 imagery received from Cycles I through V.

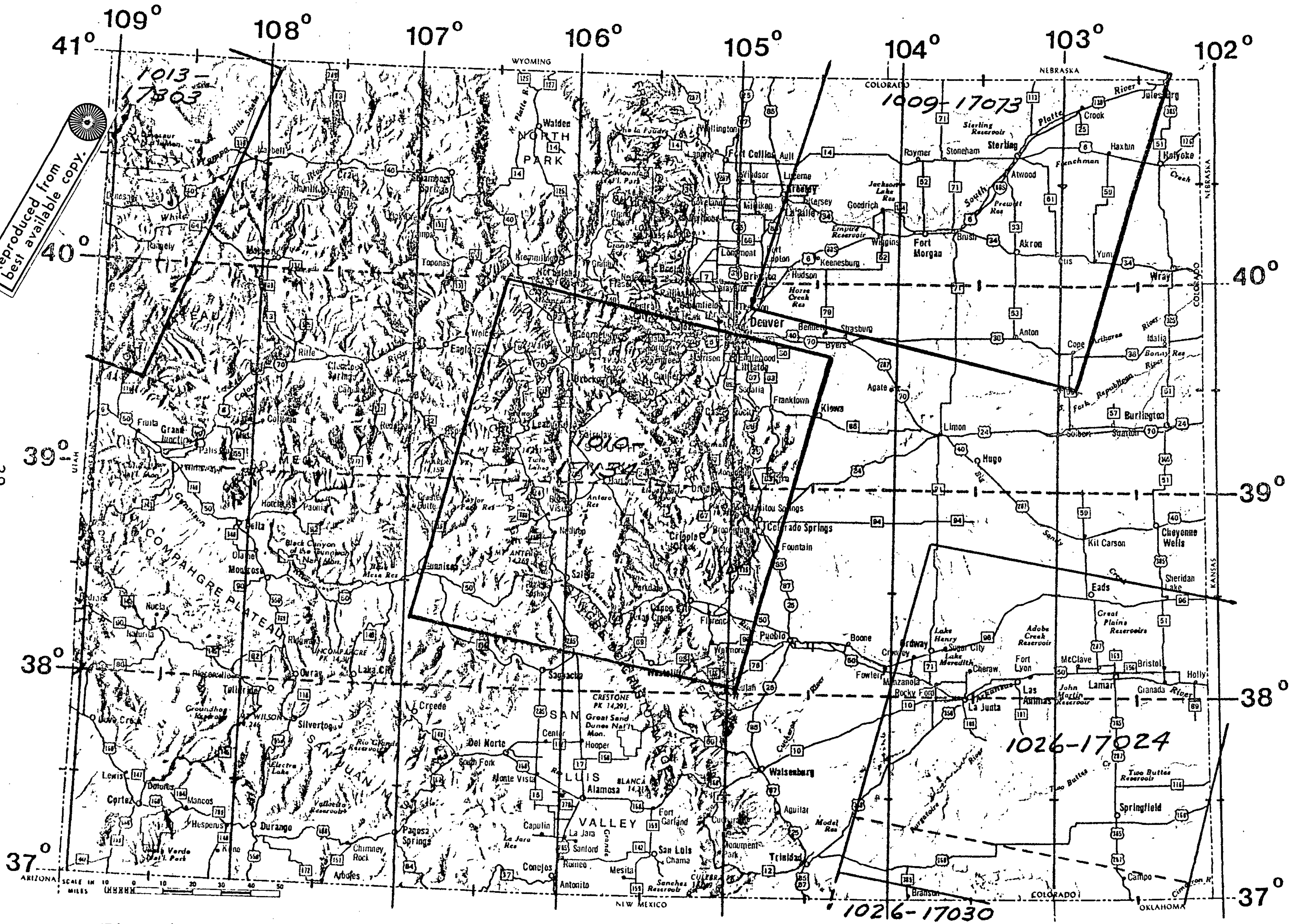

Fig. 5. Index map of Colorado, showing imagery received from Cycle I (Aug 1-18, 1972)

- 40 -

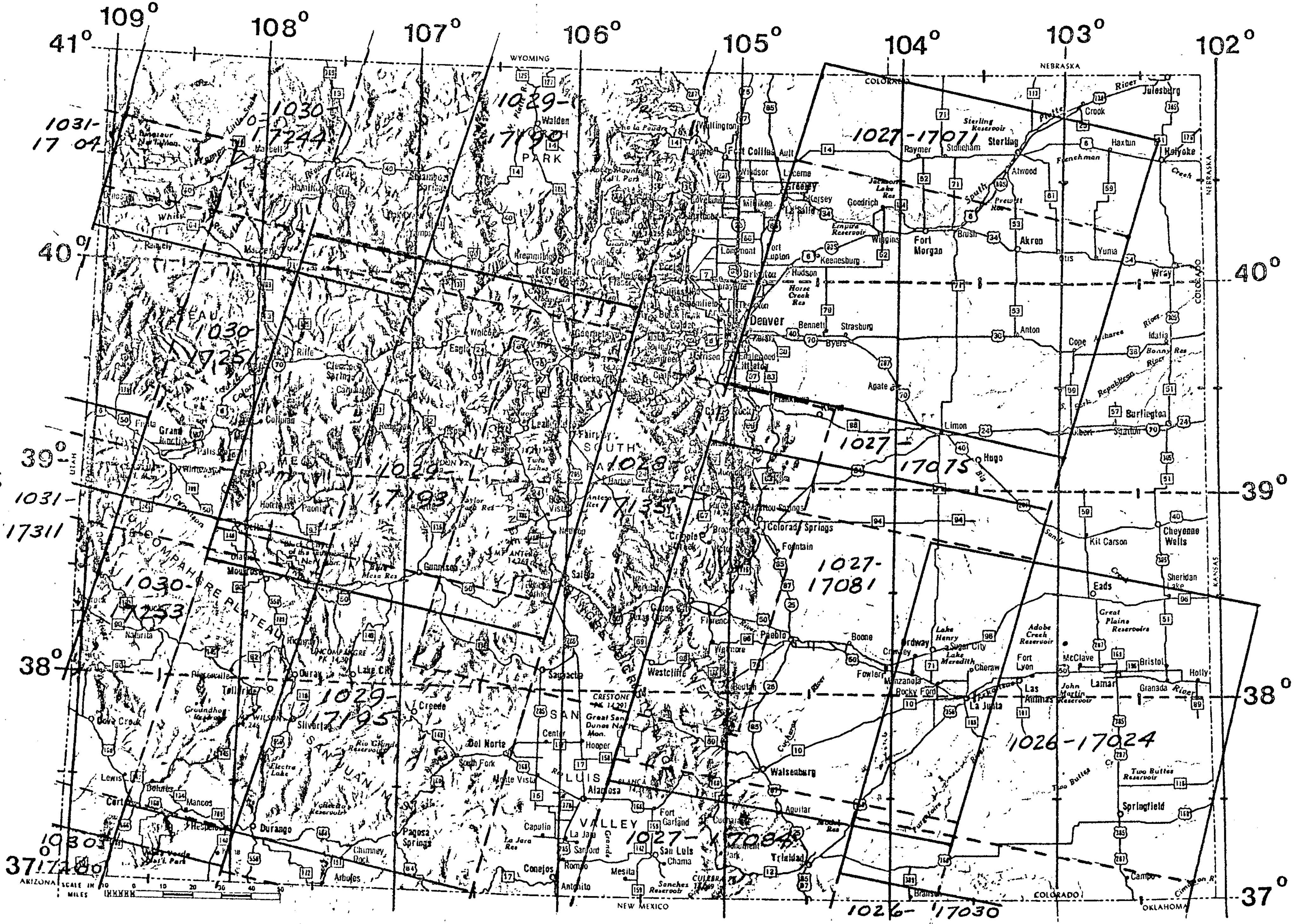

Fig. 6. Index map of Colorado, showing imagery received from Cycle II (Aug 19-Sept 5)

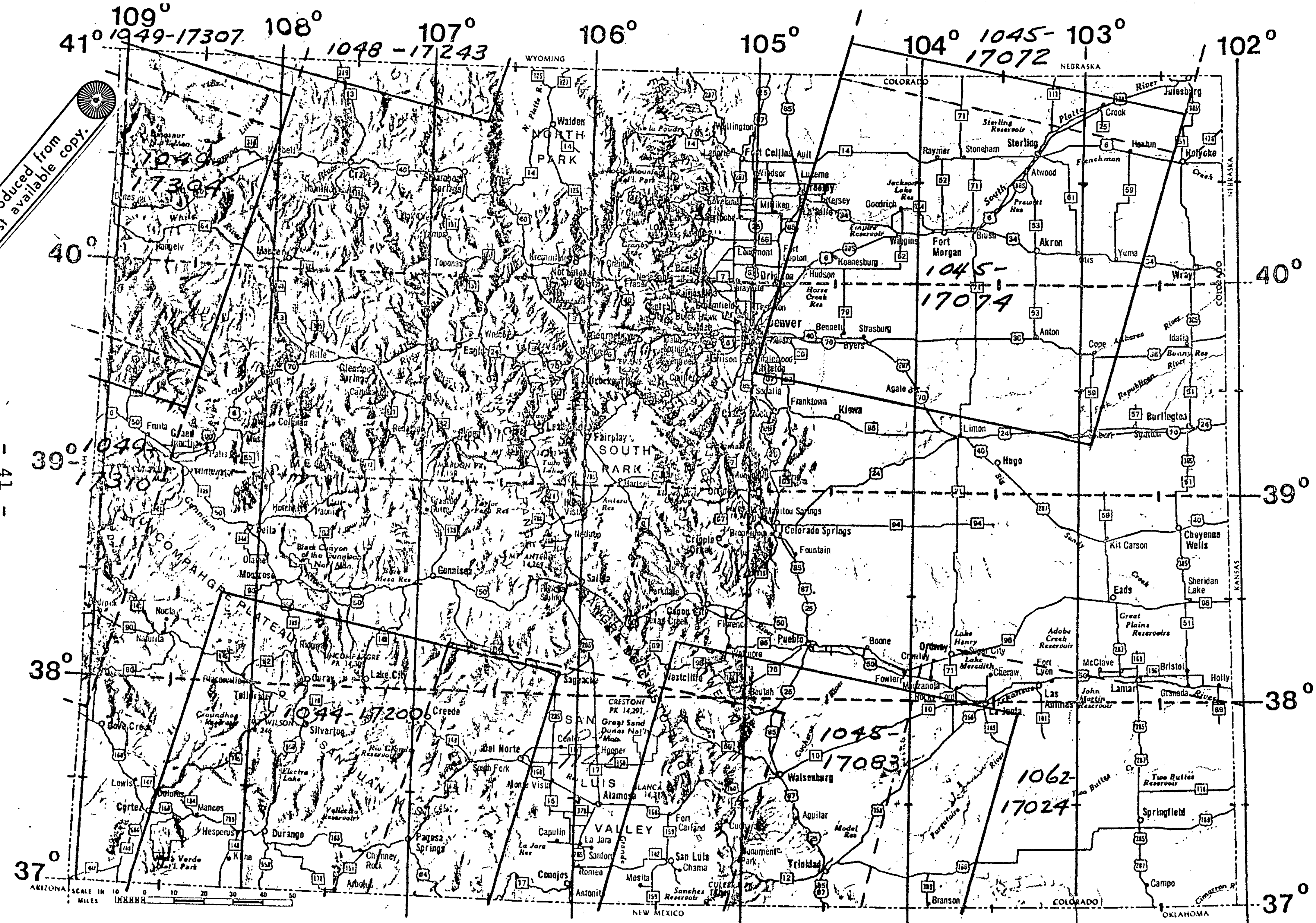

Fig. 7. Index map of Colorado showing imagery received from Cycle III (Sept 6-23, 1972)

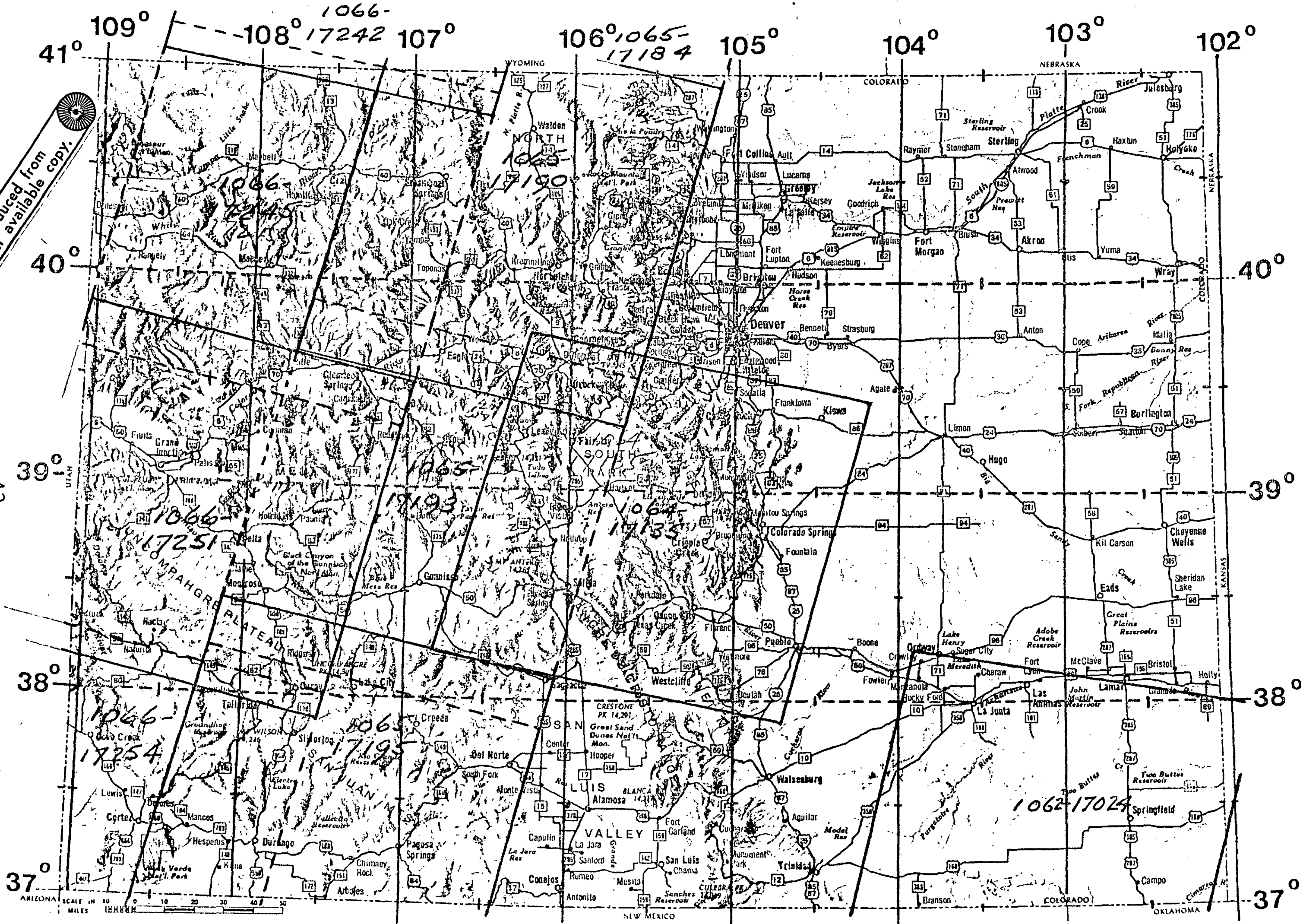

Fig. 8. Index map of Colorado showing imagery received from Cycle IV (Sept 24-Oct 11, 1972)

- 42 -

42

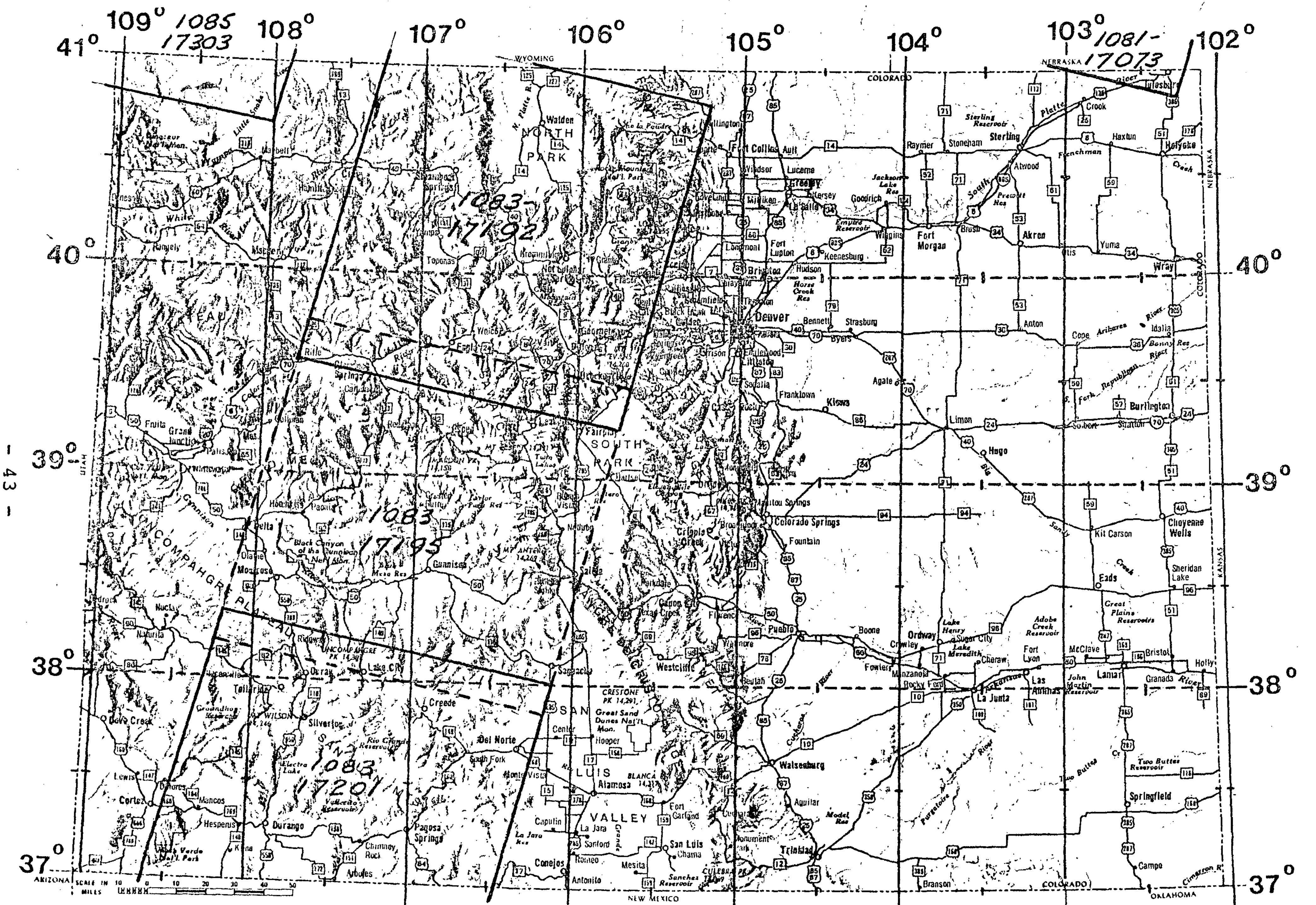

Fig. 9. Index map of Colorado showing imagery received from Cycle V (Oct 12 - 29, 1972)

- 43 -